REMOTE ACQUISITION OF HIGH QUALITY TOPOGRAPHY (LIDAR) AND MULTISPECTRAL IMAGERY DATA FOR THE RIO GRANDE THROUGH BIG BEND NATIONAL PARK: A CRITICAL NEED FOR CLIMATE CHANGE MITIGATION PLANNING

Proposal to: WaterSMART Applied Science Grants for the Desert Landscape Conservation Cooperative (Funding Opportunity Announcement No. R11SF81307)

Proposal Task Area Focus: Task Area C – Assessing and Evaluating Natural or Cultural Resources Management Practices and Adaptation Opportunities

Amount Requested: $170,082.81

Anticipated Project Duration: 18 months

Date Submitted: August 4, 2011

Submitted by: World Wildlife Fund (DUNS Number 07-484-5447) in collaboration with the Leadership Team and members of the Big Bend Conservation Cooperative, Basin and Bay Expert Science Team (BBCC) and, including National Park Service, U.S. Fish and Wildlife Service, Utah State University, Texas State Climatologist, IBWC-CILA, Environmental Defense Fund, Sul Ross State University. Federal agencies listed here are collaborators and will not receive funding as part of this proposal.

Applicant Contact Information: Mark Briggs, World Wildlife Fund, Chihuahuan Desert Program, 4969 N. Camino Antonio, Tucson, Arizona 85718; mark.briggs@wwfus.org; mkbriggs@msn.com

Geographic Focus: The Rio Grande through Big Bend National Park

Name(s) and Institution(s) of all Principal Investigator(s):
[Though key collaborators, federal personnel listed below are not requesting, nor will receive funding as part of this proposal.]

Jeff Bennett (Big Bend National Park)
Mark Briggs (Chihuahuan Desert Program, WWF)
David Dean (Utah State University)
Aimee Roberson (Fish and Wildlife Service)
Dr. Jack Schmidt (United States Geological Survey, Grand Canyon Monitoring and Research Center)
Joe Sirotnak (Big Bend National Park)
Kevin Urbanczyk (Sul Ross State University and Basin and Bay Expert Science Team)

TABLE OF CONTENTS

I. TECHNICAL PROPOSAL

A. EXECUTIVE SUMMARY

In response to the rapid and dramatic hydroecological deterioration of the Rio Grande through Big Bend, a great diversity of organizations and citizens have come together over the last decade to better understand and protect this iconic and critical river reach. The Big Bend Conservation Cooperative (BBCC) – a multi-disciplinary group of natural resource agencies, research institutions, and conservation organizations – have been organizing and implementing a wide range of river rehabilitation, scientific research activities, and climate change initiatives. More recently, the Basin and Bay Expert Science Team (BBEST) - part of an environmental flow initiative by the state of Texas – is using the best available science to recommend environmental flow regime for the major rivers of Texas. Limited understanding of the sediment dynamics of the Rio Grande and riparian vegetation change hinders river management as well as our understanding of the effectiveness of rehabilitation activities and how the river will be affected by climate change.

This proposal seeks support to use aerial-based Light Detecting and Ranging (LIDAR) and multispectral imagery to generate baseline topographic, near-channel vegetation data (maps), and extremely accurate terrain models for the 100-mile reach of the Rio Grande that flows through Big Bend National Park. Combining remotely acquired high-resolution topography via Light Detection and Ranging (LiDaR) systems and riparian vegetation measurements via multi-spectral imagery with one-dimensional flow routing model (recently constructed by Utah State University and the USGS) and a program to monitor tributary sediment input (being implemented by Utah State University, World Wildlife Fund, and Big Bend National Park), will greatly enhance our ability to quantify which future geomorphic and riparian vegetation changes, as well as aid in the construction of 1-dimensional models from which sediment transport, evacuation, and storage could be investigated under a variety of flow scenarios (Wiele and Wilcock, 2007). This LiDaR and multi-spectral imagery dataset could also provide the background structure from which models could be constructed to analyze how the river conditions might respond to changes in sediment and water runoff brought about by climate change.

Data acquired by the proposed LIDAR flyover will be used by a variety of institutes, organizations, and agencies to enhance several critical initiatives within the Desert LCC, including BBEST, BBCC, Texas Parks and Wildlife Department (TPWD), Big Bend National Park, Rio Grande Joint Venture, U.S. Fish and Wildlife Service, amongst others (please see accompanying letters of support).

B. PROJECT TECHNICAL DESCRIPTION

1. PROPOSAL GOAL

This proposal seeks support to use aerial based Light Detecting and Ranging (LIDAR) to generate baseline topographic and riparian vegetation data (maps) and extremely accurate terrain models for the 100-mile reach of the Rio Grande that flows through Big Bend National Park. LiDaR collected from an aircraft can now be used to collect topographic data over large spatial scales at a horizontal resolution less than 1 m, and at a vertical resolution of approximately 10 cm. The Digital Elevation Models (DEMs) that can be produced from these data will provide invaluable information on channel width and depth and the elevation of flood plain. These DEM's are required for planning river and border related projects, including floodplain and river riparian restoration, exotic species removal, river channel morphology studies, flood preparedness and mitigation, security risk assessment and planning, mapping riparian bird habitat and quantifying environmental flow needs.

Multi-spectral imagery will be used to classify vegetation assemblages based on leaf reflectance to produce high-resolution vegetation maps. Dean and Schmidt (2011) show that vegetation exerts considerable control over channel morphology and causes a positive feedback where channel narrowing is exacerbated by vegetation which helps trap and stabilize near channel sediment. Vegetation maps obtained from the multi-spectral imagery will provide the ability to correlate vegetation type and density to physical channel and floodplain processes such as channel narrowing/widening and floodplain aggradation/scour. These maps will also help managers quantify the success of mechanical and biological removal of invasive species so targeted removal reaches and methods can be refined.

2. BACKGROUND

The Rio Grande Through the Big Bend Region of the Northern Chihuahuan Desert

The Chihuahuan Desert is one of the three most biologically rich and diverse deserts in the world, rivaled only by the Great Sandy Tanmi Desert of Australia and the Namib-Karoo of southern Africa (Dinerstein et al. 2000). This desert encompasses nearly 250,000 square miles, stretching from the Mexican plateau, just north of Mexico City, to the Rio Grande Valley in southern New Mexico and the San Simon Valley of southeastern Arizona.

The geographic focus of this proposal is the Big Bend reach of the Rio Grande, which is named after the characteristic "bend" in the river Grande/Rio Bravo and functions as both a geographic barrier between the U.S. and Mexico as well as a vital source of water and vegetation for humans and wildlife. The core of the Big Bend region is the area occupied by six federal and state protected areas: Big Bend Ranch State Park, Big Bend National Park, Black Gap – in the U.S. – and the protected areas of Santa Elena, Ocampo, and Maderas del Carmen – in Mexico, which together encompass over 5,123 sq. miles (1,327,067 ha) (Fig. 1).

The Big Bend reach of the Rio Grande extends from the confluence of the Rio Grande and Rio Conchos 490 km downstream to Amistad Reservoir. As the only major through flowing river in this arid region, the Rio Grande/Bravo and its primary tributary, the Río Conchos in Mexico, are the lifeblood of the northern Chihuahuan Desert. However, the Rio Grande through Big Bend has experienced tremendous changes in stream flow, sediment supply, and near-channel vegetation cover owing to the construction of dams, stream flow diversions, and levees (Everitt, 1993; Schmidt et al., 2003). As a result, channel conditions over the last four decades have gone from wide and shallow to narrow and deep. These altered hydrologic and channel morphologic conditions have negatively impacted native fauna, through – via loss of high quality habitat, - and riverside towns, - through the decrease in channel capacity and accompanying increase in the frequency that these towns are flooded. In American Rivers' 15th annual report, America's Most Endangered Rivers, the Rio Grande was highlighted in the top seven as a river that “faces potential ecological collapse due to excessive consumption of its limited water supply and over-engineering of its fragile riverbed and riverside habitat.

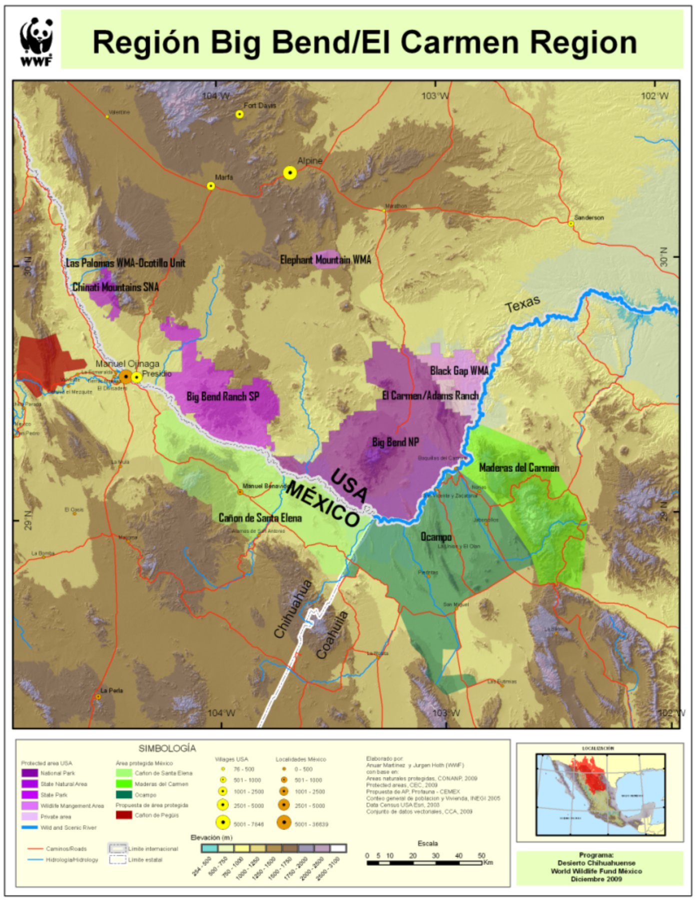

Figure 1. Map of Big Bend region, showing the Big Bend reach of Rio Grande and the federal and state protected areas.

Conservation Response

The Big Bend region of the northern Chihuahuan Desert, in general, and the Rio Grande through Big Bend is one of WWF’s priority places for conservation. Over the last decade, we have worked with protected area managers on both sides of the river to develop a broad-based response to the river’s hydroecological deterioration. An important result of this expanded work was the development of the Big Bend Conservation Cooperative, which consists of Big Bend National Park, Texas Department of Parks and Wildlife, Comisión Nacional de Áreas Naturales Protegidas (CONANP), US Fish and Wildlife Service, U.S. Geological Service, Utah State

University, Sul Ross State University, World Wildlife Fund, Environmental Defense Fund, and over 15 other agencies, organizations, and institutes on both side of the border.

Our collective scientific and conservation response has focused on conducting:

i) Scientific studies to improve our current understanding of river conditions through Big Bend;
ii) On-the-ground rehabilitation efforts in targeted sites to remove non-native species with the theory that such efforts will make underlying alluvium more vulnerable to evacuation and help to reverse channel narrowing trends;
iii) Monitoring efforts to gauge our progress toward realizing bi-national, collaborative objectives;
iv) Climate change initiatives with NOAA, CLIMAS-University of Arizona, and State Climatologists of Texas at Texas A&M University, and
v) Quantifying and securing environmental flow to help reverse channel narrowing trends.

BBCC's Climate-Related Initiatives

Given the importance of the establishment of Landscape Conservation Cooperatives to the nationwide response to climate change, it's appropriate to highlight in this proposal the BBCC's partnerships with NOAA-Sectoral Applications Research Program (NOAA-SARP), CLIMAS-University of Arizona (CLIMAS), and the Office of the Texas State Climatologist at Texas A&M University (OTSC). This proposal to the Desert LCC would add significantly to our climate-related work, providing an avenue for addressing and balancing the critical scientific needs of Big Bend natural resource managers highlighted as part of this proposal with other climate-related research and initiatives supported by our partnership with NOAA SARP.

As part of our past climate-related work, OTSC assessed current and past precipitation and temperature patterns and to better understand how these patterns will shift in the future in the Big Bend region of the Chihuahuan Desert (BB-CD) (McRoberts and Nielsen-Gammon 2010). Temperatures are projected to continue increasing throughout the 21st century, and the warming is predicted to accelerate as time goes by. Average temperatures in the BB-CD are expected to rise 3°F to 5°F by the middle of the 21st century (Nielsen-Gammon 2008). When considering interannual variability, even cool years during the middle of the 21st century will be normal or above normal relative to current temperatures.

The effects of climate change on precipitation are much less predictable, with models suggesting a slight decrease in precipitation across Texas. However, changes in precipitation are projected to be much smaller than the natural variability. For a given amount of precipitation, evaporation increases with increased temperatures and this will compound future droughts. Additionally, increased evaporation will create dwindling water supplies and the projected increase in population will further decrease water (McRoberts and Nielsen-Gammon 2010).

Warm season temperatures show less variability than cool season temperatures, so the expectation is that future summertime temperatures will be consistently warmer than what has been recorded in the 20th and early 21st centuries. The situation in the BB-CD is eye-opening because the majority of precipitation falls during the warm season. As a result, the availability of water will depend more and more on cool season precipitation, which is normally dry in the BB-CD. Therefore, in the BBCD, it is likely that – due to the natural variability of precipitation in the Chihuahuan Desert - droughts will occur and that they will take place in a warmer environment. Therefore, the best drought analogs would be those that combine high temperatures and a lack of precipitation (McRoberts and Nielsen-Gammon 2010).

Two priorities have emerged from this natural resource and climate-related research. First, is a study quantifying future flood risks and their uncertainties, combining estimates of socioeconomic damage from past flooding with climate change projections on stream flow. This priority is part of a current proposal that BBCC plans to submit to NOAA in the fall (a letter of intent for this priority was submitted in July 2011). Second, is the need to better understand how changes in channel and associated habitats may be affected by climate-related changes in stream flow. A critical step toward accomplishing this is to combine high resolution topography measured using LIDAR with a flow routing model (being developed by Utah State University, Big Bend National Park, and Sul Ross State University) to predict areas of sediment evacuation and storage. Such initiatives are essential to understanding how future climate trends might impact Rio Grande streamflow through Big Bend as well as critical to BBCC's efforts to estimate the stream flow required to meet stated restoration goals (i.e., environmental flow needs) as well as gain a deeper appreciation of how climate change might affect the general effectiveness of our other river conservation endeavors.

Description of Prior Studies that Relate To or Inform the Project

Previous studies have shown that the Rio Grande exists in disequilibrium characterized by rapid channel narrowing during moderate to low flow years, and channel widening during rare, large, long duration floods (Dean and Schmidt, 2011). During periods of low flow, non-native vegetation establishes within the channel thereby stabilizing sediment and encouraging additional sediment deposition (Dean and Schmidt, 2011; Dean et al., 2011). Channel narrowing is an undesirable process because habitat deemed essential to the native ecosystem, such as backwaters and side-channels, are filled with sediment. Between 1991 and 2008, the channel of the Rio Grande narrowed by approximately 50% through the vertical accretion of over 3m of sediment within the channel. In 2008, a large, long duration flood of nearly 1500 m^3/s widened the channel by 60 to 100 %, stripping much of the sediment that had rapidly accumulated during the 17 years prior.

Regional environmental managers hope to slow the rate and magnitude of channel narrowing expected to occur over the next couple of decades. Vegetation removal efforts through mechanical removal of giant cane, and biological removal of tamarisk are currently underway. Mechanical removal efforts are small scale, and their effectiveness is uncertain. Annual channel cross-section surveys by USU in 2 vegetation removal reaches, and 1 non-removal reach aim to quantify geomorphic changes in relation to these removal efforts. These reaches are small (2-6 km) in scope and labor intensive, and thus, the results of larger scale removal efforts are difficult to decipher. Acquisition of LiDaR would provide a topographic baseline that could be used to compliment and expand current channel surveys.

USU and GCMRC established a near-continuous suspended sediment monitoring program at two sites in Big Bend National Park. This program aims to constrain the fine sediment supply contributed by ephemeral desert tributaries as well as the amount of that sediment that is entrained by main stem Rio Grande flows and dam releases. These data will be used to recommend environmental flows of a sufficient discharge and duration in order to maximize suspended sediment downstream and prevent its accumulation within the channel. A high-resolution LiDaR dataset could provide the basis for a large scale 1-dimensional flow routing model from which data obtained from a current suspended sediment monitoring program could be incorporated. The suspended sediment monitoring program can provide boundary conditions of sediment supply and transport, and the flow routing model constructed from LiDaR could be used to test a range of flow scenarios to help guide environmental flow prescriptions mentioned above.

3. JUSTIFICATION

LiDaR

We are proposing to use aerial based Light Detecting and Ranging (LIDAR) to generate baseline topographic data and high-resolution terrain models for the reach of the Rio Grande that passes through Big Bend National Park. The Digital Elevation Models (DEMs) that this project will produce will provide a baseline topography from which to monitor channel narrowing, vertical floodplain accretion, and other geomorphic features in the future.

Fundamentally, the data collected as part of a LiDaR over-flight are critical to improving our understanding of the sediment dynamics of the Rio Grande. Our current limited understanding of water and sediment dynamics of the Rio Grande hinders development of an environmental flow management and risk assessment program. Because undesirable channel change is partly determined by the large quantities of fine sediment and gravel delivered to the Rio Grande, it is essential to understand the source areas, quantity, grain size, and timing of the delivery of that sediment. Additionally, it is important to understand the Rio Grande's competency and capacity to transport gravel. Understanding could be improved by the development of three research efforts: development of a suspended sediment budget, the development of a gravel load budget, and the development of a sediment transport routing model.

Development of a suspended-sediment monitoring program was started by USU and GCMRC in November 2010. This monitoring program is a critical step to developing environmental flow recommendations, because the program will allow development of a fine sediment budget for parts of the Rio Grande through Big Bend. The development of a suspended sediment budget will allow estimation of the quantity of sand and mud input by desert tributaries, the flux of fine sediment downstream during average main-stem Rio Grande floods or by dam releases, and the relative increase or decrease in transport downstream. These estimates will help determine the proportion of sand and mud that remains in storage in the channel and is deposited on floodplains, and the required frequency and magnitude of flows needed to promote increased transport downstream for the maintenance of channel capacity and maintenance of aquatic ecosystem function.

Funding for the installation of the paired acoustic profiler and automatic pump sampler stations were provided by GCMRC as a pilot program to contribute to nationally significant river science. This measurement program relies on field collection of depth-integrated samples necessary to calibrate the acoustic profilers and develop statistically significant suspended sediment transport relations.

The relative control that gravel exerts on channel morphology is not well understood. Recent studies show that large deposits of gravel accumulate near the mouths of tributaries (Dean and Schmidt 2010). Gravel is delivered to the Rio Grande during tributary flash floods. No data exist concerning the persistence and mobility of these newly formed gravel deposits, the relative long-term influence these features have on upstream fine sediment deposition and floodplain accretion, nor the control these features exert on channel mobility. The construction of gravel transport relations and a gravel budget would help answer these questions and help identify the minimum flows required to mobilize gravel deposits and encourage channel reorganization.

Gravel budgets could be calculated using actual measurements of bed load transport on tributaries and the main stem, by conducting morphologic analyses of change using channel surveys, or a combination of both. For logistical reasons, gravel transport measurements could more easily be done on ephemeral tributaries. These could be compared to morphologic changes measured on the main stem to calculate budgets over short reaches. Additionally, particle tracer studies could be done using painted rocks or radio-frequency identification to determine flows required for mobilization. Combining sediment transport data with high resolution topography measured using aerial-based LIDAR systems can be used to predict areas of sediment evacuation and storage and the quantity of sediment stored or evacuated (Wiele and Wilcock, 2007).

Multi-Spectral Imagery

The riparian vegetation community of the Rio Grande in the Big Bend region has changed drastically during the last century. Prior to large-scale dam construction in the early 1900s, vegetation communities were heterogeneous with sparse, flood tolerant patches of seep willow (*Baccharis glutinosa*) established on sand bars, discontinuous stands of willow (*Salix exigua*) and cottonwood (*Populus* spp.) at the channel margins, and dense thickets of mesquite (*Prosopis glandulosa*, *Prosopis pubescens*) set back from the channel margins (Ainsworth and Brown, 1933; Everitt, 1998; Stotz, 2000).

Invasion by non-native riparian species coupled with declines in flow due to dams, diversions, and drought led to a transformation of the riparian corridor. Floodplains that once supported sparse, patchy, native vegetation communities became densely vegetated by non-native species including tamarisk and giant cane (Arundo donax).

Both giant cane and tamarisk invasions have negative ecological impacts including stream flow depletions, displacement of native vegetation, degradation of wildlife habitat, and increased soil salinization (Bell, 1997; Everitt, 1998; Shafroth et al., 2005), although the relative magnitudes of these effects are debated (Shafroth et al. 2005). These species can also exert considerable control over channel morphology through bar and bank stabilization (Thorne, 1990; Gran and Paola, 2001; Griffin et al., 2005), the reduction of near-bank flow velocities and shear stresses (Kouwen et al., 1969; Kean and Smith, 2004; Tal and Paola, 2007), and sediment trapping (Schultz et al., 2003). Dean and Schmidt (2011) showed that the establishment of riparian vegetation in and near the channel of the Rio Grande causes a positive feedback by stabilizing bars and banks and promoting sedimentation such that processes of channel narrowing and floodplain accretion are exacerbated.

To date, no comprehensive effort has been undertaken to map the vegetation throughout the study area. Although the study area is large, modern multi-spectral remote sensing imagery could be used to undertake this effort. If linked with development of a map/aerial photo base, it would be possible to quantitatively evaluate the present distribution of native and non-native vegetation and link the distribution of vegetation with the distribution of geomorphic features, and future geomorphic processes.

Meeting Critical River Management Needs
Information provided by LiDaR and multi-spectral imagery will provide natural resource managers information that will greatly assist with a number of critical needs along the Rio Grande through Big Bend, including (i) prediction of geomorphic change for different environmental flow scenarios; (ii) assessment of flood risk; (iii) evaluation of habitat for key Rio Grande species; (iv) formulation of climate-adapted responses; and (v) evaluation of near-channel exotic plant eradication efforts to promote positive channel change. These needs and how the data collected using the proposed aerial-based LIDAR and multispectral imagery are summarized below.

Environmental Flow Quantification
Since dam construction in the early 1900s, the Rio Grande has experienced cycles of channel narrowing during periods of low flow and drought, and infrequent channel widening, i.e. reset, floods caused by occasional large dam releases on the Rio Conchos (>1000 m3/s, > 2 x 105 m3/s.days). Prior to dam construction, floods of this magnitude and duration had a recurrence of approximately once every 4 years. Channel narrowing following large flood events occurs rapidly through the vertical accretion of bars that evolve to become floodplains inset within the previously wider channel. There may be a flow regime that is capable of maintaining a widened channel following reset, but the primary attributes of the Rio Grande s history is one of progressive narrowing. Combining high resolution topography data acquired using aerial-based LIDAR systems with a flow routing model can be used to predict areas of sediment evacuation and storage (Wiele and Wilcock 2007). Such knowledge is key to identifying the stream flow characteristics required to mobilize near-channel sediment and maintain desirable channel conditions. Monitoring data generated by the proposed project will also be used to inform flow-control decisions, such as those made by water masters, dam operators, and water commissions throughout the Rio Grande Basin. The IBWC has agreed to consider National Park Service proposals on how treaty obligated water deliveries could be controlled to provide channel maintenance and ecosystem services. The results of the proposed project will also be applied to policy-making in local, state, federal environmental management and regulatory agencies.

Flood Risk Assessment

The near-record Rio Grande flood of 2008 had a significant impact on Big Bend Ranch State Park (Texas Parks and Wildlife Department), Big Bend National Park, and numerous riverside towns. Many of these areas were inundated for weeks and received significant damage. Visitor access to facilities inside and outside Big Bend National Park was extremely limited during and after the event. Such an event is likely to occur again. An analysis of flow records reveals that on the average, flows like this happen approximately every 12-15 years.

Federal, state and local response to the 2008 flood event was hampered by inaccurate flood forecasting. While the 2008 flow was higher than recent flows, the peak discharge was approximately 10 percent greater than peak flows observed in the early 1990s. Recent studies explain why usual flows can rise to unusual heights. Infestation by saltcedar (*Tamarix* spp.) and giant river cane (*Arundo donax*) along the Rio Grande has lead to an increase is sedimentation within the river channel, a loss of channel carrying capacity, flooding at lower discharges, growth in the elevation of the flood plain and an elevation of floods.

Habitat Evaluation

The work described in this proposal is critical to our understanding and management of fish, wildlife, plants, and habitats that are associated with the Rio Grande. As mentioned above, data collected as part of a LiDaR over-flight are critical to improving our understanding of the sediment and riparian vegetation dynamics of the Rio Grande. Sediment dynamics and riparian vegetation play a critical role in determining the type, diversity, and quality of aquatic and riparian habitats associated with the Rio Grande. Thus, gaining a better understanding of sediment dynamics and how they relate to flows and riparian vegetation in the Rio Grande will help us to better manage the river for aquatic species. Of particular interest in the Big Bend reach of the Rio Grande are rare, threatened or endangered species such as the Rio Grande silvery minnow (endangered; nonessential experimental population), the Texas hornshell (candidate), and the yellow-billed cuckoo (candidate).

The U.S. Fish and Wildlife Service is currently leading an effort to re-establish the endangered Rio Grande silvery minnow in the Big Bend area as a critical step toward the species' recovery. This effort is partially funded by the Middle Rio Grande Endangered Species Collaborative Program, as administered by the Bureau of Reclamation. This re-establishment program has been underway since 2008 and is showing significant signs of success so far.

After three annual releases of the endangered Rio Grande silvery minnow, in June 2011, the Fish and Wildlife Service and multi-agency crews sampled for silvery minnows in the Big Bend reach of the Rio Grande. The primary goal of the sampling effort was to document the current distribution of the species in Big Bend. The crews documented that silvery minnows have dispersed 15 miles upstream and almost 70 miles downstream from release sites. They also collected small young of year fish which will be examined under microscopes for species identification. This data should be available in September. After documenting silvery minnow reproduction in 2010 and this range extension in 2011, we are excited about the continued success of this recovery project that is resulting in demonstrable, on the ground improvement of this endangered species' status.

The Middle Rio Grande Endangered Species Collaborative Program in New Mexico and the Bureau of Reclamation contribute funding for our work to recover the silvery minnow in Big Bend. Partners in Texas and Mexico also include Big Bend National Park, U.S. Geological Survey, the International Boundary and Water Commission, Texas Parks and Wildlife Department, the University of Texas – Pan Am, the World Wildlife Fund, Comisión Internacional de Límites y Aguas, Secretaría de Medio Ambiente y Recursos Naturales, Comisión Nacional de Areas Naturales Protegidas, and the Instituto Nacional Ecologia.

Climate Adaptation

Our natural resource research has shown that despite the consequences of river impoundment and over-allocation of water, the frequency of flooding along the Big Bend reach of the Rio Grande has actually increased owing to changes in channel morphologic conditions (decreased channel capacity). Climate forecasts predict an increase in the frequency and intensity of convectionally driven, storms emanating from the Gulf, which may further exacerbate flooding and flood damage to riverside towns and infrastructure. Two priorities have emerged from this natural resource and climate-related research. First, is a study to quantify future flood risks and their uncertainties, combining estimates of socioeconomic damage from past flooding with climate change projections on stream flow. This priority is part of a current proposal that BBCC plans to submit to NOAA in the fall. Second, is the need to better understand how undesirable changes in the channel and associated habitats may be affected by climate-related changes in stream flow. A critical step toward accomplishing this is to combine high resolution topography measured using LIDAR with a flow routing model (being developed by Utah State University, Big Bend National Park, and Sul Ross State University) to predict areas of sediment evacuation and storage.

Evaluation of Exotic Vegetation Management

Large, dense stands of giant cane (*Arundo donax*) and saltcedar (*Tamarisk* spp.) now occupy young alluvial deposits along much of the Rio Grande. The dense stands of non-native plants effectively armor the alluvium from entrainment during small and moderate floods and induce deposition in most low-velocity areas. As noted previously, the cumulative impact of continued vertical aggradation of the floodplain and in-filling of the channel has diminished channel capacity and increased the occurrence of flooding, which has led to frequent damage of riverside towns and protected area infrastructure.

The removal of dense stands of exotic vegetation along selected reaches of the Rio Grande through Big Bend being conducted to increase vulnerability of underlying alluvium to mobilization and reverse channel narrowing trends. However, despite an emphasis on site-based monitoring, we have just limited appreciation of the channel morphological consequences of these exotic vegetation management actions. In this regard, broad scale, near-channel vegetation mapping is required, allowing a reach-wide assessment of vegetation change along treated and non-treated (control) reaches. When compared to future aerial and on-the-ground surveys, the riparian vegetation data (maps) produced by the proposed aerial LIDAR survey will allow such a reach wide assessment.

4. METHODS AND DELIVERABLES

The Remote Sensing Services Laboratory

The Remote Sensing Services Laboratory at Utah State University has been providing high quality multispectral imagery and developing a variety of applications over the last 20 years. The Lab owns and operates a Cessna Turbo TP206 dedicated to remote sensing, that houses the USU airborne multispectral digital system. Recently, the lab has teamed up with the USTAR Center for Active Sensing and Imaging which have designed and developed the LASSI (LiDaR Assisted Stereo Imager) instrument that is now approved by the FAA to operate on the USU Cessna TP206 remote sensing aircraft. The two labs have integrated both systems so that both multispectral imagery and LiDaR data can be acquired simultaneously and fused into a seamless orthorectified product.

LiDaR System

The LiDaR system uses a full-waveform Riegl Q560 LiDaR transceiver, a Novatel SPAN LN-200 GPS/IMU Navigation System. The LiDaR is capable of working at up to 1200m above ground level (agl) at a pulse rate of up to 150,000 shots per second. It has beam divergence of less than 0.5 mrad and therefore has a size of about 0.5 m at 1000 m agl. An average flying height of 1000 m is proposed for the Rio Grande corridor which, given a pulse rate of 70,000 shots per second, a flight speed of 180 kph and a scan rate of 85 Hz, will yield an average shot density of 1 shots per square meter. Given a 50% side-lap specification, an average shot spacing of 1.6 to 2 shots per square meter is anticipated. The waveform for each shot will be digitized at a rate of 500 MHz which yields a volume spacing of 0.3 m. Depending on the availability of GPS satellites and locality of differential GPS base-stations, it is anticipated that an absolute vertical and horizontal accuracy of 8 cm and 15 cm will be achieved, respectively. Figure 1 shows the LASSI LiDaR system installed in the Cessna TP206 aircraft.

As a result of the side-lap specification, we estimate 5 to 6 parallel flight lines will be needed to cover the assumptions made for this cost estimate of a one mile swath centered over the river.
LiDaR point clouds will created by combining GPS/IMU trajectory data with LiDaR scanner data using proprietary system-specific software. The points will then classified into using custom macros developed for differentiating vegetation, buildings, bare-earth, and points generated by system noise. At the customer's discretion, other attributes that can be added to points include LiDaR return intensity, echo number, and rgb color. The classification algorithm will be custom tuned to the Rio Grande River terrain using visualization of results in representative areas.

A digital elevation model (DEM) compatible with ArcGIS will be created from the randomly distributed LiDaR points. It is anticipated that a cell size of 1 square meter will provide a relatively good representation of the terrain, given the nominal shot density of 2 shots per square meter anticipated. However, this cell size can be easily tailored to customer requirements as the project progresses.

Multispectral System

The multispectral portion of the airborne system consists of three Kodak Megaplus 4.2i digital cameras with interference filters forming spectral bands in the green (0.545-0.555 µm), red

(0.665-0.675 μm) and near infrared (NIR) (0.790-0.810 μm) wavelengths. The cameras are mounted alongside the LiDaR through a porthole in a Cessna TP206 aircraft, dedicated for remote sensing missions. The cameras are controlled through special software using Epix boards in a fast desktop computer, mounted in the equipment rack. The system digital cameras are calibrated against a radiance standard. On the day of the flight, a standard reflectance panel with known bi-directional properties is set up in a central location to the study area. An Exotech 4-band radiometer is mounted looking down onto the panel from nadir, measuring incoming irradiance at one-minute intervals. This information is used to calculate the reflectance of the pixels in the spectral imagery. The shortwave images will be acquired at a nominal overlap of 80% along the parallel flight lines planned to cover the river corridor. The 900 m swath width will overlap laterally at least 30% with the adjacent flight lines. The individual spectral band images will be geometrically corrected for radial distortions and also radiometrically adjusted for lens vignetting effects and registered into 3 band images to be merged with the LiDaR data.

The 3-band images will be ortho-rectified, using the geometric calibration parameters of the cameras and the LiDaR terrain parameters along with the positioning information from the LiDaR Novatel navigation system supported with appropriate ground control. The rectified images will be mosaicked into larger image strips along the flight lines. The rectified image strips will be calibrated in terms of reflectance prior to the formation of the final mosaic covering sections of the floodplain.

The system also comprises a FLIR SC640 thermal infrared camera which acquires thermal images in the 8 – 12 □m range. This instrument is mounted through a different porthole aligned with the multispectral system cameras. Thermal imagery will not be acquired for this project.

Data and Image Acquisition Campaign

LiDaR data will be acquired over a 100 mile reach of the Rio Grande River through Big Bend National Park with the specifications described above. The data acquisition would occur over a period of 6 days including 2 days for the round trip from Logan to Texas. Approximately 20 hours of flight time over the river is estimated to acquire the necessary LiDaR data. Due to the meandering nature of the Rio Grande, sections of the river will be flown using blocks of parallel flight lines.

High-resolution short wave (green, red and near-infrared) and LIDAR data would be acquired with the USU airborne multispectral digital system and the LASSI system over 50 mile reaches of the Rio Grande River, to be determined later. We estimate a total of 6 hours of flight time acquiring LiDaR data and multispectral imagery over the area and 20 hours for the round trip from Logan, Utah to the local airport. We estimate that the LiDaR and multispectral imagery will be acquired over a period of one to two days, under clear sky conditions. An additional two days are reserved for the commute from Logan, Utah to Texas and back.

Deliverables

1. LiDaR point cloud data that is classified and colorized with rgb values. The classification will include bare earth, low vegetation, high vegetation and structures (if any). A variety of tile sizes and point densities will be provided according to customer specifications.
2. Color ortho image mosaic at 0.25 meter resolution
3. Final report describing the data and methodology, main features of the imagery and LiDaR data.

5. POST-PROJECT BENEFITS (performance measures)

This proposal seeks support to use aerial-based Light Detecting and Ranging (LIDAR) and multispectral imagery to generate baseline topographic, near-channel vegetation data (maps), and extremely accurate terrain models for the 100-mile reach of the Rio Grande that flows through Big Bend National Park. Big Bend National Park, Fish and Wildlife Service, World Wildlife Fund, BBCC, BBEST, Rio Grande Joint Venture, and others have identified this activity as priority need and anticipate the collected data being used in a variety of ways that will provide a multitude of benefits. Indeed, how well the collected data are used to generate information required for improving management of the Rio Grande through Big Bend will be the ultimate performance measure of this project.

Proper planning of future restoration and rehabilitation projects demands a complete understanding of the nature and extent of the impacts of recent past flood events (e.g., the flood of 2008) on channel morphology and vegetation distribution. The proposed mapping of vegetation and channel and floodplain geomorphology will allow the measurement and evaluation of: 1) the effectiveness of climate change mitigation strategies' 2) the effectiveness of on-going vegetation removal efforts and changes in the composition of native and non-native riparian species;, 3) the impact of vegetation removal on flood stage by use of numerical flow models; and 4) measure sediment transport during flows that cause floodplain scour and fill. Many of the needs and benefits that an aerial-based LIDAR survey will provide have already been described in the Justification' section, but are summarized again below.

Environmental Flow Quantification - Combining high resolution topography data acquired using aerial-based LIDAR systems with a flow routing model can be used to predict areas of sediment evacuation and storage (Wiele and Wilcock 2007). Such knowledge is key to identifying the stream flow characteristics required to mobilize near-channel sediment and alter channel morphology in a manner that widens the channel and increases channel capacity, which are two key restoration objectives that have been put forward by BBCC as elements toward improving habitat quality for many native wildlife species and reducing flood risk and damage to streamside towns and infrastructure. In the context of environmental flow assessment and quantification, BBEST and BBCC will be the two groups that have immediate use and access to the LiDaR acquired data.

Riparian Vegetation Mapping – The proposed aerial LiDaR survey will provide multispectral digital imagery of the Rio Grande through Big Bend National Park. Images will be acquired, processed into a rectified mosaic of each study reach, classified into vegetation communities based on field ground-truthing of key vegetation species. This reach-scale data set will address two pressing river management needs that are reflected by BBCC and Rio Grande Joint Venture: assessing the channel morphologic response of exotic plant removal and allowing an assessment of riparian habitat for resident and migratory bird species.

The removal of dense stands of exotic vegetation along selected reaches of the Rio Grande through Big Bend being conducted to increase vulnerability of underlying alluvium to mobilization and reverse channel narrowing trends. However, despite an emphasis on site-based monitoring, we have just limited appreciation of the channel morphological consequences of these exotic vegetation management actions. In this regard, broad scale, near-channel vegetation mapping is required, allowing a reach-wide assessment of vegetation change along treated and non-treated (control) reaches. When compared to future aerial and on-the-ground surveys, the riparian vegetation data (maps) produced by the proposed aerial LIDAR survey will allow such a reach wide assessment.

Mapping floodplain elevations and riparian vegetation are critical to RGJV's planning process to assess current riverside bird habitat and to better understand the potential for flood plain and riparian habitat restoration in the Rio Grande channel.

Understanding Impacts of Climate Change – Through our current partnerships with CLIMAS, OTSC-Texas A&M University, and NOAA-SARP, BBCC has a much greater appreciation of what the future climate picture might look like for western Texas. The next major climate-related challenge is to understand how future climate trends might impact Rio Grande streamflow through Big Bend and how those impacts will affect our estimates of the stream flow required to meet stated restoration goals (i.e., environmental flow needs) as well as the general effectiveness of our other conservation endeavors.

As with all basin-scale conservation projects, our efforts in Big Bend are multi-faceted with long-term goals whose realization will require the completion of a variety of actions. Of all the challenges our team faces, understanding climate change and its impacts on both natural resource conditions and the effectiveness of our conservation measures probably best fit this long-term description. Some actions or steps have been successfully taken, with many future steps required. Acquiring high resolution topography data and multispectral digital imagery is one of these critical steps. Combining these data with a flow routing model can be used to predict areas of sediment evacuation and storage under different flow scenarios (Wiele and Wilcock 2007). Accomplishing this will provide the foundation for assessing how climate change might alter river discharge probabilities (Bouwer et al. 2010). This, in turn, provides the foundation for adapting our current river restoration actions to better meet our river management objectives in a changing climate.

C. PROJECT TEAM, IMPLEMENTATION SCHEDULE AND OTHER NECESSARY INFORMATION

1. DESCRIPTION OF ROLES OF PROJECT TEAM MEMBERS

MARK BRIGGS – Briggs hydroecologist with World Wildlife Fund's Chihuahua Desert Program and is lead on this grant proposal. As such, is main responsibilities include coordinating and overseeing the implementation and completion of all proposed project activities and deliverables.

JEFF BENNETT is a Physical Scientist with the National Park Service station with Big Bend National Park and the Rio Grande Wild and Scenic River. Jeff will coordinate efforts associated with ground-truthing vegetation and channel morphology data.

AIMEE ROBERSON is a biologist with the Fish and Wildlife Service and has worked on the Big Bend reach of the Rio Grande for many years. She will assist with efforts associated with ground-truthing vegetation and channel morphology data, as well as interface with the Rio Grande Silvery Minnow Technical Team on how best to apply the acquired LiDaR and multispectral data to habitat mapping efforts.

DR. JACK SCHMIDT is Chief of Science, USGS, Grand Canyon Monitoring and Research Center and for numerous years has been involved in scientific investigations to better understand the Rio Grande's current and past hydrologic condition. Jack will participate in coordination meetings and review project deliverables.

DR. JOE SIROTNAK is a botanist at Big Bend National Park and will assist Jeff Bennett in coordinating ground truthing efforts as well as help review all deliverables associated with this effort.

DR. KEVIN URBANCZYK is Chair of the State of Texas Upper Rio Grande Basin to Bay Expert Science team (BBEST). This team is charged with making instream flow recommendations that can sustain a sound ecological environment in the reach of the Rio Grande from Presidio, Texas to Amistad reservoir. Kevin will help coordinate ground truthing efforts and review deliverables.

USU REMOTE SENSING SERVICES LABORATORY - The Remote Sensing Services Laboratory at Utah State University has been providing high quality multispectral imagery and developing a variety of applications over the last 20 years. The laboratory will conduct the over-flight of the Rio Grande through Big Bend National Park, acquiring LiDaR data and multispectral images, classifying point clouds into terrain and vegetation, and calibrating and classifying the imagery to produce a vegetation cover thematic map, conduct one week of ground truth field work in Texas, and produce a final report.

USU SCIENTISTS DAVID DEAN AND CHRISTOPHER NEALE will ground truth the multispectral imagery to help in the production of classified vegetation maps. Ground truth data and imagery would be processed using ERDAS Imagine, ARCGIS, or similar software to produce the high-resolution vegetation maps.

2. QUALIFICATIONS OF PROJECT TEAM MEMBERS

MARK BRIGGS, M.S. natural resource scientist with the World Wildlife Fund's Chihuahuan Desert Program. He has worked on restoration, research, and monitoring efforts on numerous rivers throughout the southwestern U.S. and northern Mexico. His work with the Chihuahuan Desert program has focused on developing a bi-national response to bringing back the Rio Grande near Big Bend in the context of a changing climate. Over the last twenty years, he has been involved in a variety of river conservation efforts with similar objectives to understand the causes of ecological decline, develop strategies to improve bottomland ecological conditions, and monitoring programs to both gauge the effectiveness of restoration efforts as well as understand how and why ecological conditions are changing. In addition to river conservation work along the Rio Grande, Mark has worked on other river binational efforts, including the Colorado River Delta, Santa Cruz in Sonora, Mexico, and San Pedro River in Sonora, Mexico. [email: mark.briggs@wwfus.org]

DAVID DEAN, M.S., Research Associate, Utah State University. Mr. Dean conducted historical analyses of geomorphic change on the Rio Grande as part of a Master's thesis. Findings of this research are published in two peer-reviewed scientific journals (Dean and Schmidt, 2011; Dean et al., 2011). Mr Dean is a co-PI on two projects monitoring geomorphic change of the river channel and floodplain. Monitoring projects include: (1) annual topographic surveys of three reaches of the Rio Grande for the purpose of measuring annual changes to the channel morphology, and for constructing 1-dimensional hydraulic models for predicting thresholds for floodplain inundation. (2) monitoring suspended sediment transport at two gages in Big Bend National Park for the purposes of constraining fines sediment contributions from ephemeral tributaries and the capacity of transport by main-stem Rio Grande flows. The ultimate goal of these projects are to link suspended sediment transport measurements to changes in channel and floodplain form and riparian vegetation removal. Findings of these studies provide guidance for rehabilitation efforts along the river corridor.

JEFF BENNETT is a professional geologist licensed within the state of Texas. He is native to the southwest and has been working on water resource and environmental issues for 20 years. His recent work with the NPS includes setting and defining and implementing priorities for research and management of the Rio Grande, its tributaries and watersheds; project development and management relating for water resources and key landscape processes; bi-national project development and implementation; providing technical assistance to local and regional planning groups: participating on the Science Sub-Committee of the Desert Landscape Conservation Cooperative; and working with colleagues to provide leadership to the Big Bend Binational Conservation Cooperative (BBCC), a partnership of natural resource managers and others interested in conservation of the greater Big Bend-El Carmen region of the Chihuahuan Desert in Texas, Chihuahua, and Coahuila. Jeff serves on the Science Team for development of state environmental flow standards for the Rio Grande and is a voting member of the Far West Texas Regional Water Planning Group.

AIMEE ROBERSON is a Fish and Wildlife Biologist who works for the Fish and Wildlife Service's Ecological Services division in Alpine, Texas. She has a B.A. degree in geology from Macalester College and an M.S. in Conservation Biology from the University of Minnesota. Aimee co-leads the recovery program to re-establish the endangered Rio Grande silvery minnow in the Big Bend reach of the Rio Grande and also works on various other projects, primarily related to the Ecological Services' Endangered Species, Migratory Birds, and Partners for Fish and Wildlife programs. Aimee plays a leadership role in the Big Bend Conservation Cooperative and is working with conservation partners to expand that effort into a binational partnership focused on improving the ecological condition of the Rio Grande and the larger Big Bend-Rio Bravo region of the northern Chihuahuan Desert. Before moving to Texas, Aimee worked for the Fish and Wildlife Service in New Mexico on projects related to recovery of the Rio Grande silvery minnow and the Middle Rio Grande Endangered Species Collaborative Program.

DR. JACK SCHMIDT is Chief of Science, USGS, Grand Canyon Monitoring and Research Center. As a professor at Utah State University, Dr. Schmidt has led hydrologic and geomorphic investigations on the Rio Grande since 2003, and has provided managers with the basic understanding of the processes which govern the morphologic form of the channel and floodplain of the Rio Grande (Schmidt et al., 2003; Dean and Schmidt, 2011; Dean et al., 2011). He is currently a PI and co-PI on two monitoring projects which aim to link morphologic changes to sediment transport and the effects of non-native vegetation.

JOE SIROTNAK is a botanist at Big Bend National Park and has been involved for over a decade on Rio Grande conservation issues. He received his B.Sc. in Forestry at the University of Vermont, and M.Sc. and Ph.D. in Ecology at Idaho State University. He has been at Big Bend National Park since 2000, where he is responsible for vegetation management, including exotic plant management, ecological restoration, T&E plant species conservation, and ecological monitoring. He has been active in securing funding, planning, and implementing several large-scale exotic plant management and restoration projects in riparian and upland habitats in cooperation with an international consortium of private and government conservation organizations. [email: joe_sirotnak@nps.gov]

USU REMOTE SENSING SERVICES LABORATORY - The Remote Sensing Services Laboratory at Utah State University has been providing high quality multispectral imagery and developing a variety of applications over the last 20 years. The Lab owns and operates a Cessna Turbo TP206 dedicated to remote sensing, that houses the USU airborne multispectral digital system. Recently, the lab has teamed up with the USTAR Center for Active Sensing and Imaging which have designed and developed the LASSI (LiDaR Assisted Stereo Imager) instrument that is now approved by the FAA to operate on the USU Cessna TP206 remote sensing aircraft. The two labs have integrated both systems so that both multispectral imagery and LiDaR data can be acquired simultaneously and fused into a seamless orthorectified product.

DR. KEVIN URBANCZYK is Director of the Rio Grande Research Center and Professor of Geology at Sul Ross State University in Alpine, Texas. He has been involved in specific research regarding the Rio Grande since 2004 as the Principle Investigator of the Sustainable Agricultural Water Conservation in the Rio Grande Basin project. His research has focused on water quality issues related to spring inflow in the Rio Grande Wild and Scenic River section of the Rio Grande, on monitoring the morphology of selected sand and gravel bars in Boquillas Canyon, Big Bend National Park and on evaluating the chemical characteristics of hyprheic water adjacent to the Rio Grande in Big Bend National Park. He is also Chair of the State of Texas Upper Rio Grande Basin to Bay Expert Science team. This team is charged with making instream flow recommendations that can sustain a sound ecological environment in the reach of the Rio Grande from Presidio, Texas to Amistad reservoir.

3. LETTERS OF SUPPORT INDICATING DESERT LCC RESOURCE MANAGER BACKING AND IN-KIND SUPPORT

Please see justification section as well as letters of support.
The following agencies and organizations have submitted letters in support of this proposal:

- Basin and Bay Expert Science Team (BBEST) [IN-KIND DOCUMENTED]
- Big Bend National Park
- Fish and Wildlife Service
- Rio Grande Joint Venture
- Texas Parks and Wildlife Department
- U.S. Geological Survey, Austin, Texas
- World Wildlife Fund [IN-KIND DOCUMENTED]

4. CONNECTION TO BUREAU OF RECLAMATION PROJECT ACTIVITIES

The project area for this proposal, the Rio Grande where it flows through Big Bend National Park, is heavily influenced by the Bureau of Reclamation’s Rio Grande Project. The Rio Grande Project furnishes irrigation water supply for about 178,000 acres of land and electric power for communities and industries in south-central New Mexico and west Texas. These water diversions and those in Mexico on the Rio Conchos result in a depleted river that is highly altered from its natural state and requires active management for improving ecosystem health and lessening the effects of flooding in riverside communities. This proposal will supply river and natural resource managers with data that will enable them to be more effective in accomplishing these tasks.

The Bureau of Reclamation also administers the Middle Rio Grande Endangered Species Collaborative Program (MRGESCP) in New Mexico. The MRGESCP is a partnership involving 16 current signatories organized to protect and improve the status of endangered species along the Middle Rio Grande of New Mexico while simultaneously protecting existing and future regional water uses. Two species of particular concern are the Rio Grande silvery minnow and the southwestern willow flycatcher.

Program activities include water acquisition and management, habitat restoration, endangered species monitoring, and silvery minnow propagation. The program also provides funding in support of the Fish and Wildlife Service's program to re-establish the Rio Grande silvery minnow in the Big Bend reach of the Rio Grande.

Congress provided approximately $115.8 million to the Bureau of Reclamation from FY2001 to 2009 with an approximate non-federal match of $12.7 million to support Program activities. Reclamation serves the leadership role for the Program. Accomplishments include acquisition of over 158,290 acre-feet of supplemental water from willing program participants from FY2003-2009.

5. IMPLEMENTATION SCHEDULE AND MILESTONES

Activity and Milestones	Months Following Project Approval
1. Team organizational meeting	1
2. Finalization of flight plan and schedule	3
3. Flight – multi-spectral and LIDAR acquisition	5
4. Classification of point clouds into vegetation and topography	8
5. Multispectral image acquisition and ortho stacking,	10
6. Calibration and classification of the imagery to produce a vegetation cover thematic map	12
7. Ground truthing and classification rectification	14
8. Final report and deliverables	18

6. STRATEGY FOR DISSEMINATING RESULTS

The results of this effort will be disseminated, transferred, and communicated to partners within the Desert LCC in the following ways:

- There are several websites that we will consider for housing the information produced as part of this effort. The final report for this effort will be place on WWF's Chihuahuan Desert website for easy access by all Desert LCC partners. We will also work with the, USGS to house the data on their National Elevation Dataset (please see their letter of support for this project), which will provide national exposure. In addition, we closely with the International Boundary Water Commission and they have offered to be a host for the information as well;;
- Mark Briggs (WWF and lead investigator on this proposal) and Aimee Roberson (FWS) have been involved in numerous meetings in the past regarding the development of the Desert LCC. Both continue to actively participate in steering committee meetings,

allowing numerous opportunities to communicate the results of this proposed effort to partners and explore other creative ways to communicate the results of this effort to all Desert LCC participants;

- As part of a proposal submitted by BBCC members to the Commission of Environmental Cooperation (CEC), website development was included in support of BBCC and Big Bend-Rio Bravo initiative efforts. Our understanding at this point is that this proposal has passed the review process and is cleared for funding. If this is confirmed, the websites will be an ideal home for all products developed from this effort;
- Briggs is leading efforts to develop a river restoration guidebook that is based on the results of a conference convened last year on river restoration. One of the chapters of the guidebook focuses on providing a framework for river practitioners on how to incorporate climate change information into restoration strategies. Outlining the concepts put forward as part of this proposal and the niche of LCCs in addressing natural resource needs in a changing climate will be highlighted as part of this chapter;
- Briggs will be presenting at the *Iberian Congress on River Restoration* in Leon, Spain in mid-October 2011. Though too early for presenting results of the work proposed here, the Congress provides an unique opportunity to discuss the proposal as well as the value of the LCC framework to an international audience interested climate adaptation;
- We anticipate at least one peer-reviewed journal article that incorporates the results of this project into sediment routing models. Given the wide range of institutes, agencies, and organizations involved in the Rio Grande, we anticipate several additional peer-reviewed articles that stem from this work. Yet, difficult at this point to identify the specific teams and the article focus.
- Data collected under this proposed project will be made available to resource managers, agencies, and organizations who work on the Rio Grande in the Big Bend area. Data will be posted to a website that is currently being developed as a data sharing tool and forum for conservation in the Big Bend Chihuahuan Desert Region.

7. LITERATURE CITED

Ainsworth, C. M. and F.P. Brown. 1933. Report on the changes in regimen of the Rio Grande in the valley below since construction of Elephant Butte Dam, 1917-1932: Unpublished report to the International Boundary Commission, 84 pp., 44 exhibits.

Bell, G. P. 1997. Ecology and management of Arundo donax, and approaches to riparian habitat restoration in southern California. Plant Invasions: Studies from North America and Europe 103-113.

Bouwer, L.M., Bubeck, P. and Aerts, J. 2010. Changes in future flood risk due to climate and development in a Dutch polder area. Global Environmental Change 20:463–471.

Dean, D.J. and J.C. Schmidt. 2011. The role of feedback mechanisms in historical channel changes of the lower Rio Grande in the Big Bend region. Geomorphology 126, 333-349.

Dean, D.J., Scott, M.L., Shafroth, P.B., Schmidt, J.C., 2011. Stratigraphic, sedimentologic, and dendrogeomorphic analyses of rapid floodplain formation along the Rio Grande in Bend Bend National park, Texas. Geological Society of America Bulletin, 123, 1908-1925.

Dean, D. J. and J.C. Schmidt. 2010. Monitoring geomorphic response to exotic plant removal on the Rio Grande in the Big Bend region: an initial assessment: Logan, UT, Utah State University, final report, National Park Service task agreement J7130080065, 32 p.

Everitt, B. L. 1998. Chronology of the spread of tamarisk in the central Rio Grande. Wetlands 18(4): 658-668.

Gran, K. and C. Paola. 2001. Riparian vegetation controls on braided stream dynamics. Water Resources Research 37(12): 3275-3283.

Griffin, E. R., J. W. Kean, et al. 2005. Modeling effects of bank friction and woody bank vegetation on channel flow and boundary shear stress in the Rio Puerco, New Mexico. Journal of Geophysical Research-Earth Surface 110:(F4).

Kean, J. W. and J. D. Smith. 2004. Flow and Boundary Shear Stress in Channels with Woody Bank Vegetation. Riparian Vegetation and Fluvial Geomorphology: Hydraulic, Hydrologic, and Geotechnical Interaction. Washington, D.C., American Geophysical Union. Water Science and Application 8: 237-252.

Kouwen, N., T. E. Unny, et al. (1969). "Flow retardance in vegetated channels." Journal of Irrigation and Drainage Engineering, American Society of Civil Engineering 95(2): 329-342.

McRoberts, B. and J. Nielsen-Gammon. 2010. Historic and Future Droughts in the Big Bend Region of the Chihuahuan Desert. Project Final Report submitted to World Wildlife Fund. Available at Office of the State Climatologist, Texas A&M University, College Station, Texas, 248pp.

Schmidt, J.C., Everitt, B.L., Richard, G.A., 2003. Hydrology and geomorphology of the Rio Grande and implications for river restoration. Aquatic Fauna of the Northern Chihuahuan Desert, Spec. Publ. 46, edited by G.P. Garrett and N.L. Allan, pp. 25-45. Museum of Texas Tech Univ., Lubbock, Tex.

Schultz, M., H.-P. Kozerski, et al. 2003. The influence of macrophytes on sedimentation and nutrient retention in the lower River Spree. Water Research 37: 569-578.

Shafroth, P. B., J. R. Cleverly, et al. 2005. Control of tamarix in the Western United States: Implications for water salvage, wildlife use, and riparian restoration. Environmental Management 35(3): 231-246.

Stotz, N. G. 2000. Historic Reconstruction of the Ecology of the Rio Grande/Rio Bravo Channel and Floodplain in the Chihuahuan Desert, World Wildlife Fund: 1-151.

Tal, M. and C. Paola. 2007. Dynamic single-thread channels maintained by the interaction of flow and vegetation. Geology 35(4): 347-350.

Thorne, C. R. (1990). "Effects of vegetation on riverbank erosion and stability." Vegetation and Erosion: Processes and Environments: 125-144.

Wiele, S. M. and P. R. Wilcock. 2007. Reach-averaged sediment routing model of a canyon river. Water Resour. Res. 43(W02425): 16 pp.

II. OTHER REQUESTED INFORMATION

A. POTENTIAL ENVIRONMENTAL IMPACTS

None

B. REQUIRED PERMITS AND APPROVALS

Only approval we foresee is clearance for the flight plan over Mexican airspace. We plan to request clearance once funding is approved and do not foresee any problems. As a precaution, we have already discussed this matter with IBWC and they have offered to assist us with their colleagues in Mexico if challenges present themselves.

C. FUNDING PLAN AND LETTERS OF COMMITMENT – see budget and letters from WWF and BBEST documenting in-kind.

D. OFFICIAL RESOLUTION – To be submitted within 30 days of proposal due date

E. PROJECT BUDGET APPLICATION

Budget Proposal – [budget details submitted electronically]
Budget Narrative
SF-424 A